Development of a Dynamic Model of Quality Control Circles: A Case of ABC Packaging Company

Ijaz Yusuf[1]
Tashfeen Mehmood Azhar[2]

Abstract

Quality control circles are considered an effective tool in the organization to best utilize the potential of the workforce. The objective behind using quality control circles is to use employees' brains to generate savings and create an impact on the bottom-line of the company. The framework of the quality control circles shown in Table 2 proposed the structured seven steps strategy to use the workforce's potential for continuous improvement in the organization. Companies confront multi-faceted issues and challenges in the operational processes and corporate excellence thus mainly depends upon the effective and efficient quality controls to overcome the product, process, machine, and material related issues that hamper the production efficiency, quality of the product, and overall productivity of the company. This paper attempts to develop the system dynamics model of quality control circles based on normalized data of the case company. Participation in quality control circles is voluntary in nature and passion to learn and improve is the intrinsic motivation for employees and organizations to join these circles. Employee involvement to participate and produce creative ideas in these circles is the key to the success of these quality-enhancing programs (Jerman et al. 2019) and model outcome depicts the same story. The quality control circle model indicates that a set of inter-related and interdependent skills and behaviors are a necessary condition to increase participation in the quality

[1] Assistant Professor, University of Management and Technology, Pakistan;
[2] Adjunct Professor, University of Management and Technology, Pakistan.
Correspondence concerning this article should be addressed to Ijaz Yusuf, University of Management and Technology, Pakistan. E-mail: ijaz.yusuf@umt.edu.pk

control circles and productivity of projects under consideration. The computer-based software STELLA is used for programming the model of quality control circles using the generic structures of the company under study. Underlying feedback structures and interactions among various variables makes the model closer to the real-life setting.

***Keywords**:* computer simulation, employee involvement, project savings, quality control circles, systems dynamics

1. Introduction

Continuous improvement is a mandatory practice in every organization's quality programme (Van & Pretorius, 2014). From quality inspection to quality performance awards, improvement is an essential element for organizational development. Creativity and innovation have become important realities of today's business world. The companies who are capable of innovating faster than the rival firms can manage to excel quickly in the given competition. To explore people's intellectual potential and use it for organizational betterment and growth is the need of the day. Quality Control Circles were initiated by Japan in 1962 (Ishikawa, 1985) to use employees' brainpower for continual improvement in every stage of the manufacturing process. The concept was so powerful that just in a few years it was adopted by almost every organization in Japan which helped the country to achieve unprecedented economic growth and prosperity. Later, many other countries of the world adopted this approach with different names such as quality improvement teams, productivity improvement teams, small group activities, and Kaizen teams (Rohrbasser et al., 2019) with the same aspiration of tapping human capital's potential and incorporate changes in the systems (Salaheldin, 2009; Ishikawa, 1970). Continuous improvement is just a philosophy that encourages all the employees in an organization to perform their tasks effectively and efficiently (Yusuf, 2005). Employee involvement and motivation lead to cost-saving and creation of impact at the bottom level productivity goals in the organization. The outcome of the employee involvement in quality control circles projects must be translated into financial terms. This is the knowledge gap that needs to be addressed by using the mixed method approach and simulation modelling framework of system dynamics to determine the complexity and dynamism of different variables over time. It is pertinent to understand that quality circles are not only restricted to quality, instead they consider all kinds of improvements in the complete supply chain and value chain process.

The objective of this research paper is to develop a simulation-based model of the quality improvement teams or quality control circles that can be used to identify areas of improvement for project savings, enhancing the ability for continuous improvement, and building the quality culture within the organization (Yusuf & Azhar, 2018). This paper thus deals with the identification of important factors of the quality circles and its link with savings generation while simultaneously addressing the quality and productivity issues. Employee involvement and quality culture is the dream of every organization. Every company believes in the tacit knowledge of the employee but does not know how to tap the employee potential for the betterment of the organization (Arrfou, 2019). This study portrays the potential of human capital and employee commitment that unveils the underlying structures to gain insight into the model and find out the policy interventions for better financials in terms of project savings.

2. Literature Review

2.1. Background

A quality circle is a "group of factory workers from the same area who usually meet for an hour each week to discuss their quality problem, investigate causes, recommend solutions, and take corrective actions when authority is in their purview" (*IAQC).* That leads to employee empowerment and involvement in the process improvement activities. There are multiple objectives of the quality circles, but the main objective is to use the human potential for the good of the company (Hill, 1991; Rohrbasser et al., 2018) and to bring the tacit knowledge to the surface. QCC members are free to select the group leader and circle secretary. Quality control circles can choose any topic as a theme if it is based on SMARTY (specific, measurable, achievable, result-oriented, time bound, and yield-based) principle.

There have been different definitions and interpretations of quality among scholars and practitioners. For instance, William Edwards Deming calls quality “a predictable degree of uniformity and dependability suited to the market at the lowest cost”. Juran sees quality as “fitness for use” and fitness for function (Juran, 1985). Deming’s theory of profound knowledge defines quality as the reduction of variation (Stepanovich, 2004). Similarly, according to many scholars, quality is a way of managing the organization (Feigenbaum, 1991) and meeting the customer requirements (Mikalauskas, Statnickė, Habánik, & Navickas, 2019). Cost reduction is the result of process improvement and reducing the waste level within the organization. High scrap, increased number of defective units, rework, customer rejection, and low productivity are a few interrelated and interdependent factors that can be managed through quality orientation. Poor quality means more scrap, a higher level of rework and defectives are in abundance that kills the profitability of the organizations. That is the reason companies earn quality certifications like ISO 9001, ISO 45001 along with quality improvement self-initiatives like 5S, total quality control, total productivity maintenance, and the Six Sigma approach. Quality auditing (Yusuf & Azhar, 2018; Arrfou, 2019) is another quality practice to enhance supply chain performance and improve productivity. The goal of all these efforts is to bring improvement in processes and reduce the cost of operations. Quality control circles is a way to involve the employees (Jerman, Erenda, & Bertoncelj, 2019; Kumar et al., 2020) encourage them to identify the problems and root cause, invest authority to initiate the corrective measures to solve the day to day operational problems (Ishikawa, 1970; Yusuf, 2005).

3. Research Methodology

Saeed (2014) describes system dynamic as a versatile methodology to gain insight into the problem under investigation. System Dynamics (SD) concept was conceived in the late 1950s by Professor Jay Forrester at the Massachusetts Institute of Technology (Forrester, 1968). System dynamics is a computer-based modeling approach for analyzing and solving complex problems through policy design and analysis (Sterman, 2000). System dynamics focuses on the structure and behaviour of systems due to interactions of the positive and negative loops. Behaviour of the model as the outcome of feedback loops creates an understanding of the structure-behavior link. System Dynamics model must help to organize the information more understandably by linking the past to the present and showing how present conditions arose, then extending the present into persuasive alternative futures under a variety of scenarios determined by policy alternatives (Forrester, 1980). If dynamic behaviour arises from feedback within the system, finding effective policy interventions requires understanding system structure. The development of the quality control circle model requires the modeler himself to operate in feedback mode. Industrial dynamics is a powerful modeling tool to study the flow of material, flow of information, and many interconnected, interlinked, and inter-related dynamic variables having feedback notion.

System dynamics is a computer-based modelling framework that can effectively deal with complex, dynamic, and multidisciplinary problems. It requires many phases from conceptual to technical i.e. from cognitive schemes of the problem to the policy design, and from policy intervention to behavioral and operational improvements. Followings are the phases highlighted for the modelling process shown in Table 1.

Table 1.
Phases of System Dynamics Modelling

Phases	Description	Nature	Research Inquiry
Phase 1	Problem Identification	Conceptual	Qualitative Reflection
	Problem Definition	Conceptual	Qualitative Reflection
	System Perspective	Conceptual	Qualitative Reflection
	Reference Mode-Historical Data	Conceptual	Qualitative Reflection
Phase 2	System Conceptualization	Conceptual	Qualitative Reflection
	Causal Loop Diagram	Conceptual	Qualitative Reflection
	Influence Diagram	Conceptual	Qualitative Reflection
	Dynamic Hypothesis	Conceptual	Qualitative Reflection
Phase 3	Level-Rate Block Diagram	Technical	Quantitative Inquiry
	Stock-Flow Diagram	Technical	Quantitative Inquiry
	Model Formulation	Technical	Quantitative Inquiry
	Model Representation	Technical	Quantitative Inquiry
	Model Structure	Technical	Quantitative Inquiry
Phase 4	Equation Writing	Technical	Quantitative Inquiry
	Model Simulation	Technical	Quantitative Inquiry
	Model Testing and validation	Technical	Quantitative Inquiry
	Model Behaviour and evaluation	Technical	Quantitative Inquiry
	Experimentation and Policy Exploration	Technical	Quantitative Inquiry
Phase 5	Understanding and redefining phase 3 and phase 4	Conceptual-Technical	Inductive-Deductive Logic
Phase 6	Re-designing the structures and perception maps (graphical functions) for policy design	Conceptual-Technical	Inductive-Deductive Logic

Phase 1 and 2 describe the qualitative reflection based on the information collected through the case study method. Phase 3 and 4 explain the quantitative information and technical part of the model based on real-life setting and initial conditions of the company by normalizing the values of the case company to hide the propriety information of the company. System dynamics is like a mixed-method approach where qualitative and quantitative information is used to draw inferences and conclusions. Causal loop diagrams test hypothesis based on symbols used in Appendix A and equations shown in Appendix C. They represent the technical stream of the model while unveiling the underlying structures of the case company.

3.1. Positive and Negative Causal Loops

Causal loop diagramming technique (Forrester, 1968; Sterman, 2000; Yusuf & Azhar, 2018) is used to provide the linkages between various variables in the form of positive and negative loops. A positive loop is often defined by the fact that an initial change in any factor eventually induces further self-change in the original direction (Richardson & Pugh, 1981). A positive loop reinforces the change and amplifies the deviations (Petermann et al., 2019). Link polarity represents the connection between two variables and loop polarity represents the nature of the loop, either reinforcing or balancing. Loop dominance decides the behavioural growth or equilibrium state. When a feedback loop response to a variable opposes the original perturbation, the loop is negative or goal-seeking. The negative loop is usually interpreted as" a change in one element is propagated around the circle until it comes back to change that element in a direction opposite to the initial change" (Meadows et al., 1974). The outcome behaviour is considered the result of interactions of positive and negative loops (Inman et al., 2020)

3.2. Level and Rate Variables

System dynamics is essentially a modelling methodology made up of two basic elements i.e. "Level" and "Rate" (Nielsen & Nielsen, 2015). The technical phase begins with level and rate variables. Feedback structure can be portrayed through equations or stock-and-flow diagrams (Richardson & Pugh, 1981). Levels reflect on conditions within the system at a given point in time.

Stocks emerge if we suddenly freeze the activity within the system. Levels are just like the bathtubs in the sense that they accumulate or collect flows. Rates represent the stream of activity associated with stocks. Flows are depicted by a conduit pipe through which goal-seeking activities flow (Sterman, 2000).

4. Model Structure and Behaviour

Case Company

ABC Packaging is selected as a case because after successfully completing the ISO 9001 certification it wants to start a quality improvement initiative similar to Japan Quality Control Circles. The case company has started the journey of the quality circle under the name of Quality Improvement Teams within the company. The company initially started with two teams in the offset printing section. Later on, the same arrangement was implemented in all sections of the carton line including paper store, coating, cutting & creasing, and folding & gluing sections. All sections of the carton line of the ABC packaging were provided training for the seven basic but widely used tools like a flow chart, Pareto diagram, scatter plot, check sheets, Ishikawa diagram, histogram, and control charts (Sokovic et al., 2009).

The data was obtained from the company using in-depth semi-structured interviews, the company's official documents, and check sheets highlighting chronological details of quality circles. Interview questions were designed mostly open-ended following the guidelines given by the previous researchers. Normalized values of the initial conditions are shown in Appendix B. Code of conduct of quality control circles are provided in Figure 1, and the seven-step strategy is highlighted in Table 2. Code of conduct and seven-step strategy are the two main drivers that help to achieve operational excellence in terms of productivity enhancement through generating savings while tapping the human capital.

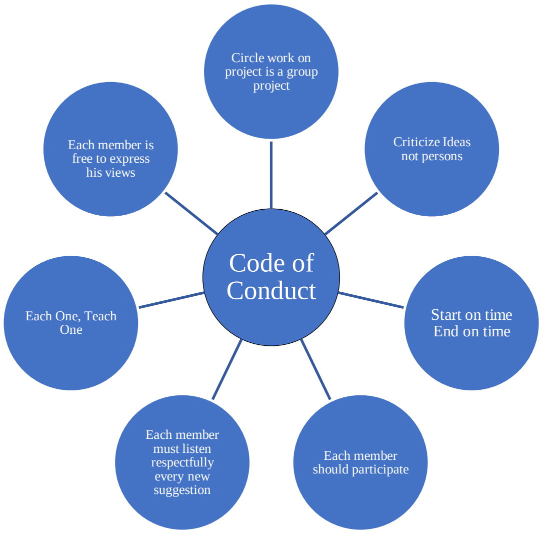


Figure 1. Code of Conduct of Quality Control Circles

Feedback Structure

The system dynamics model was developed using simulation software STELLA that contained 38 variables, 4 stocks, 6 flows, 28 convertors, 19 constants, 2 graphical functions or table functions, and 15 equations. It is the 4th order differential equation with associated flows (Forrester, 1968) that generates the oscillatory waveform. Model is a combination of reinforcing and balancing loops and behaviour generated is the results of interactions of these loops (Lane, 2007). There are two types of loops i.e. reinforcing loops and balancing loops that are as under:

The reinforcing loops are:

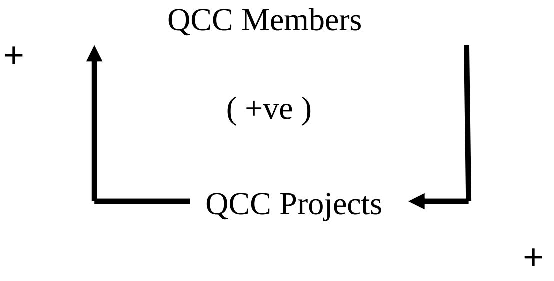


Figure 2. QCC Members and QCC Projects

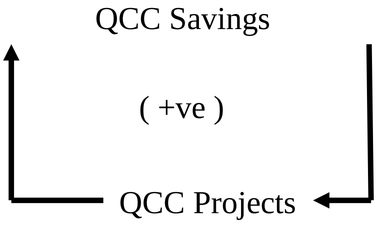


Figure 3. QCC Projects and QCC Savings Loop

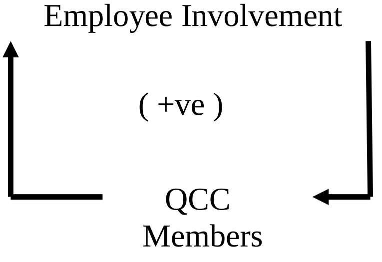


Figure 4. Employee Involvement and QCC Members Loop

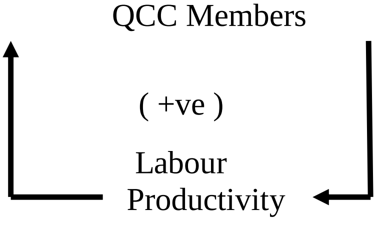


Figure 5. QCC Members and Labour Productivity

The balancing loops are:

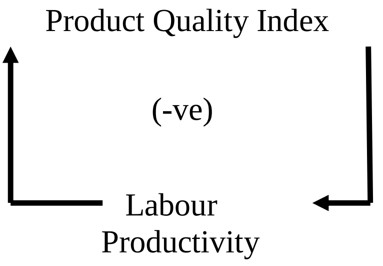


Figure 6. Product Quality Index and Labour Productivity Loop

Figure 2 shows a positive loop. More QCC members mean there are more QCC projects because each project is usually limited to 4 to 8 members. More numbers of projects indicate that each QC circle is motivated to generate more savings as the result of the stock of savings is increasing as shown in Figure 3. The company has taken various initiatives like awareness campaigns, job rotation, and participation incentives that encourage employee involvement, and consequently, there are more QCC members and enhanced labour productivity as highlighted in Figure 4 and Figure 5. Figure 6 represents the balancing loop to try to seek the balance.

Table 2.
Seven Steps Strategy

Steps	Description	Statistical Tools
Step 1	Select the theme	Brainstorming, Multi-voting, Graph, Why-Why Analysis. 5W & 1H method
Step 2	Data collection and analysis	Check sheets, Process Chart, Flow Diagram, Pareto Chart
Step 3	Identify the root cause	Pareto Chart, Cause and Effect Diagram, Scatter Diagram, Histogram
Step 4	Plan and Implement the solution	PDCA Cycle, Control Charts

Step 5	Confirm the results	Control Charts, Design of Experiments
Step 6	Standardize the solution	Quality Assurance Management System, Work Instructions, SOPs
Step 7	Reflect on the process	Findings and measures have been deployed on all similar processes.

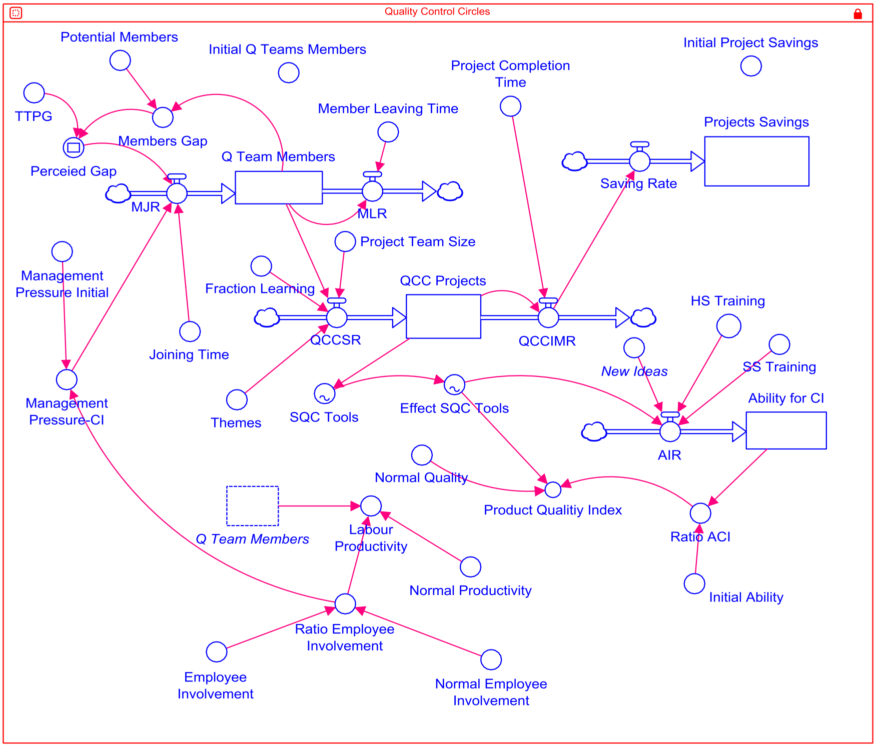


Figure 7. *Block Diagram of the Quality Control Circles (Symbols from Appendix A)*

Model Validation

Model validation (Pidd, 2010) gives confidence to the reader as well as to modeler. Various tests for model validation have been conducted. Details of validation are provided below.

Dimensional Consistency

Each variable in the model has a certain unit of measure and all the equations written in the model have dimensional consistency that reflects the real-life representation (Forrester & Senge, 1980; Qudrat-Ullah, 2010; Yusuf & Azhar, 2018).

Structure Verification

All the variables that are part of the model structure mentioned in the literature (Qutrat-Ullah, 2008) and the company structure that leads to structure verification shown in Table 3.

Table 3.

Structures Adopted from Literature

Variables/Structures	Sources
QCC Circles	(Anderson et al., 1995; Ishikawa, 1985; Yusuf & Azhar, 2018; Salaheldin, 2009)
QCC Projects	(Sila & Ebrahimpour, 2005; Anderson et al., 1995; Tan et al., 1999; Yusuf & Azhar, 2017; Salaheldin, 2009)
QCC Members	(Sila & Ebrahimpour, 2005; Anderson et al., 1995; Tan et al., 1999; Yusuf & Azhar, 2017; Salaheldin, 2009)
Ability to Continuous Improvement	(Yusuf & Azhar, 2018; Salaheldin, 2009)
Training Hours	(Sila & Ebrahimpour, 2005; Ahire et al., 1996; Kaynak, 2003; Tan et al., 1999; Yusuf & Azhar, 2018; Salaheldin, 2009)
Product Quality Index	(Sila & Ebrahimpour, 2005; Ahire et al., 1996; Tan et al., 1999; Yusuf & Azhar, 2018; Anderson et al., 1995)
Learning	(Sila & Ebrahimpour, 2005; Tan et al., 1999)

Extreme Condition Verification

This test is deployed to verify the behaviour of the model structure. The selected variables must be justified in the extreme condition (Qudrat-Ullah, 2008; Sterman, 2007; Forrester & Senege, 1980) and should exhibit the logical behaviour if there are no potential members to be the part of quality control circles, there is no tasks accomplishment (as shown in Figure 8), QC Team member must be zero, and consequently, there are no savings (see Figure 9 and Figure 10).

Figure 8. Labour Productivity is zero when no QCC Team Member

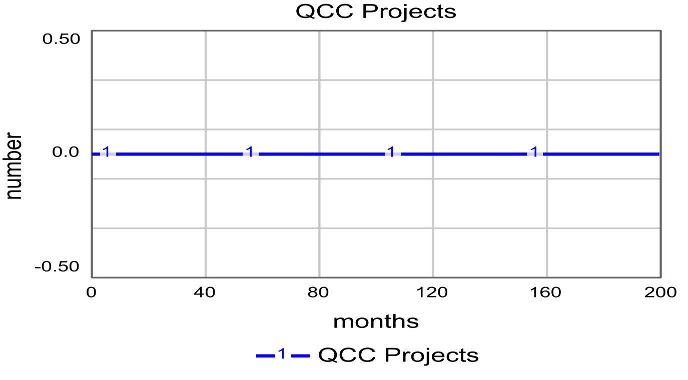


Figure 9. QCC Projects are zero when no QCC Team Member

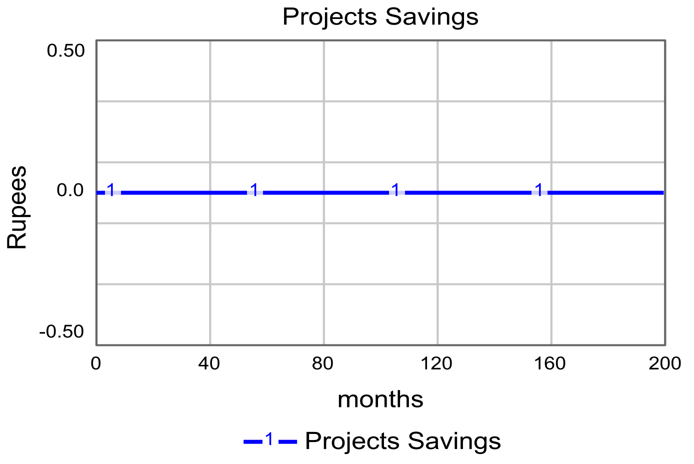


Figure 10. Projects savings are zero when no QCC Team Member

Parametric Verification

Parameter verification means comparing model parameters to the observation of the real-life system (Forrester & Senge, 1980; Sterman, 1987). Parametric values are consistent with the relevant knowledge of the case company and support is also obtained from the company documents, archival materials, judgmental opinions, participant experience, and expert opinion of the top management. Appendix B indicates a list of variables with base run values and Appendix C indicates the modelling equations.

Behaviour Reproduction Test

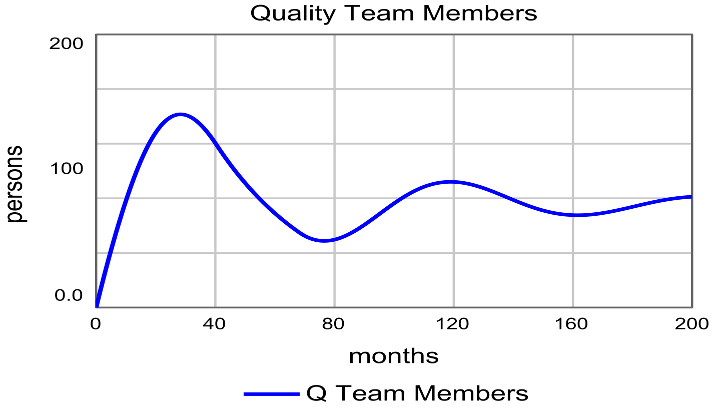
This test is being carried out for the validation of the model behaviour. Behavioral validity is to compare the model-generated behaviour to the observed behaviour (Steman, 2007; Qudrat-Ullah & Seong, 2010) of the case company. Base run values represent the reference model of the ABC Packaging.

5. Policy Analysis

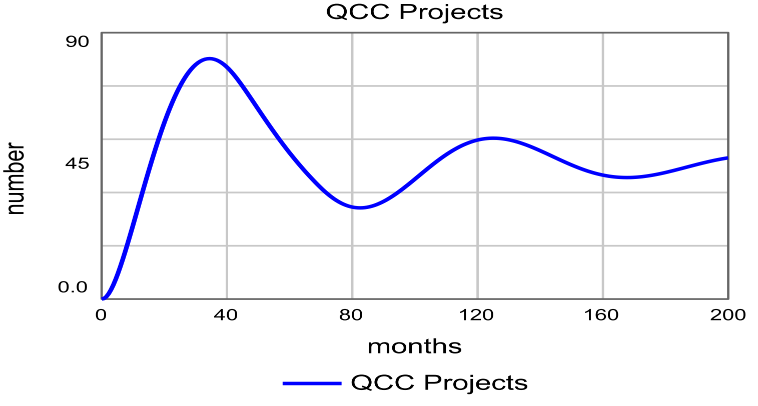
Models created for policy design perspective must incorporate multiple patterns potentially existing in the system and observed and recorded at different times and locations so that the mechanisms of change from one pattern to another can be searched through experimentation (Saeed, 1992). In this model, policies are designed and explored based on parametric changes. Multiple simulations are run exploring plausible policies. The output of these simulations is presented as a time plot and phase plot (Saeed, 2013) for a better understanding of the reader. To answer the research questions base run results of the model are discussed. Employee involvement motivates the member to conceive new projects for quality and productivity improvement and generate savings. More QCC projects mean more people are involved in QCC activities and consequently more savings may be generated as an outcome. The certain number of company employees is the staff constraint that reflects the stock adjustment process and QCC projects equilibrium state.

Base Run Result of Underlying Structure of QCC

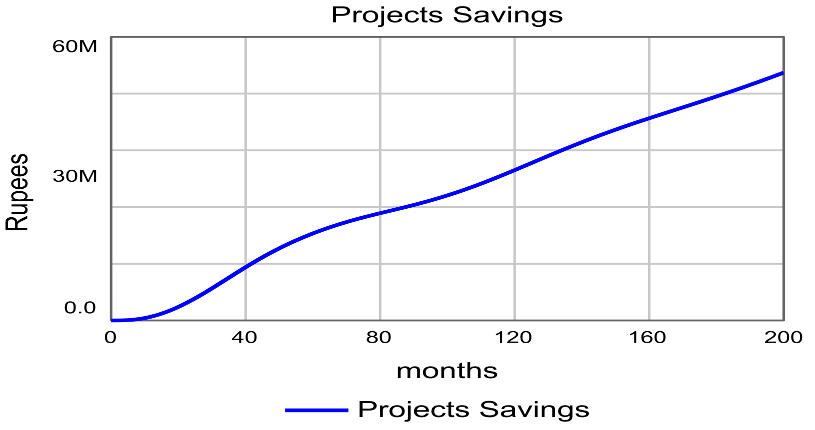
Base run values are the result of the underlying structure of the quality control circles. Employee involvement and sharing the benefits of the quality control circles indicate that the code of conduct of quality circles is followed and each circle has completed the seven steps strategy religiously using the statistical quality control tool. In the beginning under the motivational awareness sessions and production incentives, the number of QCC members is high which was settled down over time. As can be observed in graphs 1 through 5, project savings are the proven fact and the impact on the company's bottom line in terms of cost savings. In the beginning, the quality of team' members start increasing, and then due to the dominance of the balancing loop it tries to maintain the status quo position shown in graph 1; QCC projects follow the same curve pattern shown in graph 2 as the number of projects depends upon the QCC members. Projects savings and product quality index start increasing as the project continues solving the day to day operational problems shown in graph 3 and graph 4 respectively. Labour productivity reaches the maximum level and then acquiring the oscillatory waveform achieves the equilibrium state shown in graph 5. The Scatter diagram (see graph 6) shares the surprising results irrespective of the reduction of the number of projects overall savings is increasing.



Graph 1. Quality Team Members

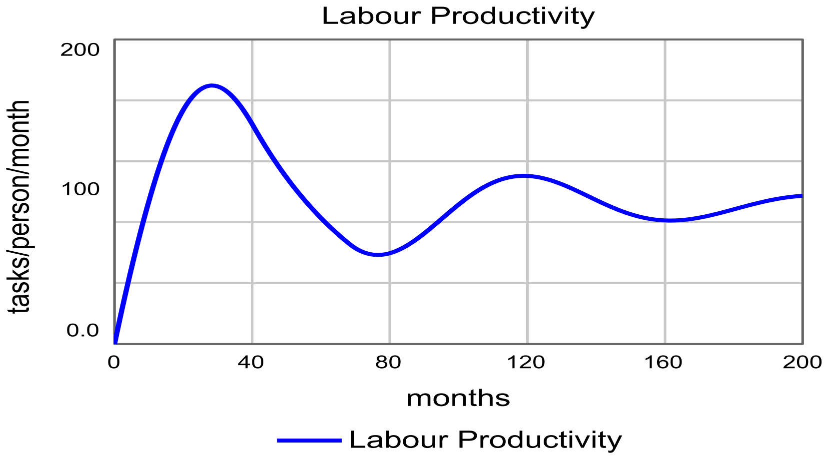


Graph 2. Quality Control Circle Projects

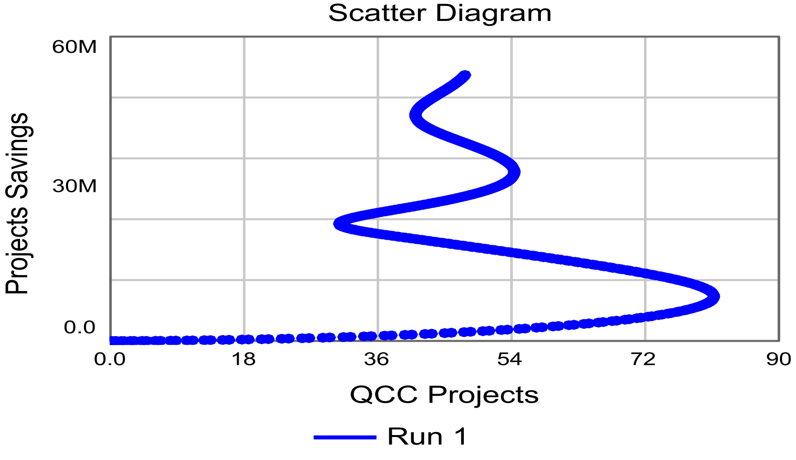


Graph 3. Projects Savings

Graph 4. Product Quality Index



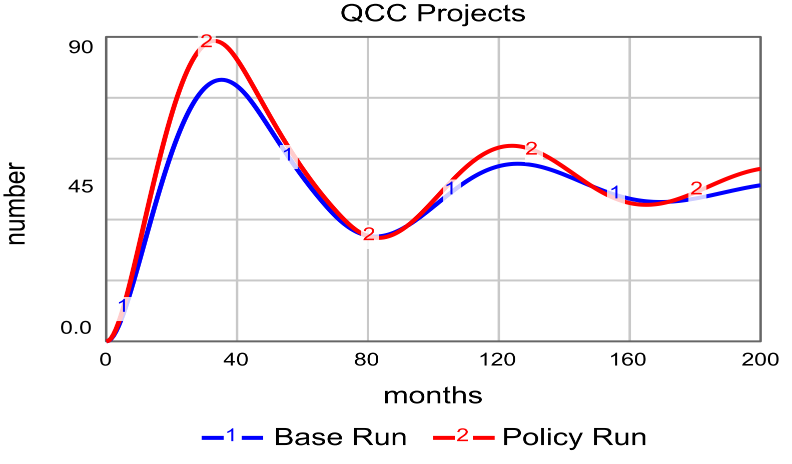
Graph 5. Labour Productivity



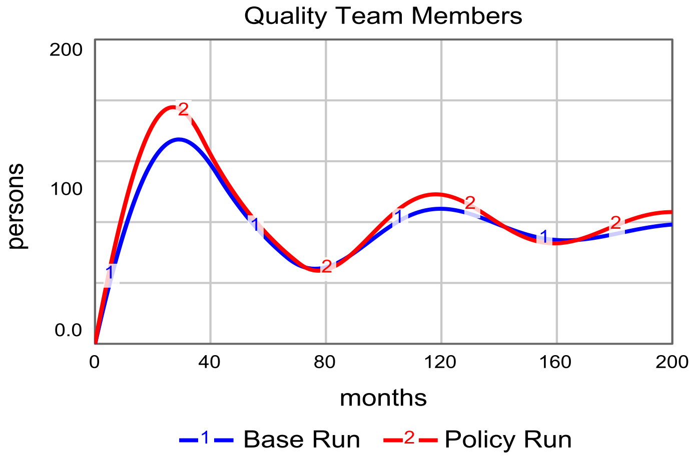
Graph 6. Scatter Diagram between QCC Projects and Project Savings

Policy Run 1 Increasing the Management Pressure (70 percent to 85 percent)

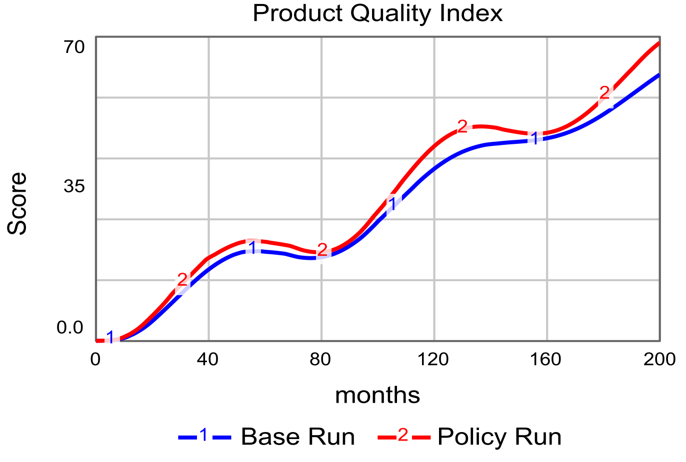
This parametric based policy is suggested based on the management approach. For instance, when the company started to generate savings, there was a motivation for the management that they should increase pressure on the quality manager and quality control circle facilitators to ensure the timely conduction of the QCC meetings, availability of the resources, and support to accomplish the corrective measures suggested by the QCC team members. Management focus is measured in the interval scale of 0 to 100 (zero to hundred) in terms of a percentage (see details in graphs 7 through 12). The graphs from 7 to 12 indicate that QCC members and QCC projects after few oscillations achieve the equilibrium state whereas QCC project savings and product quality index keep on increasing over time.



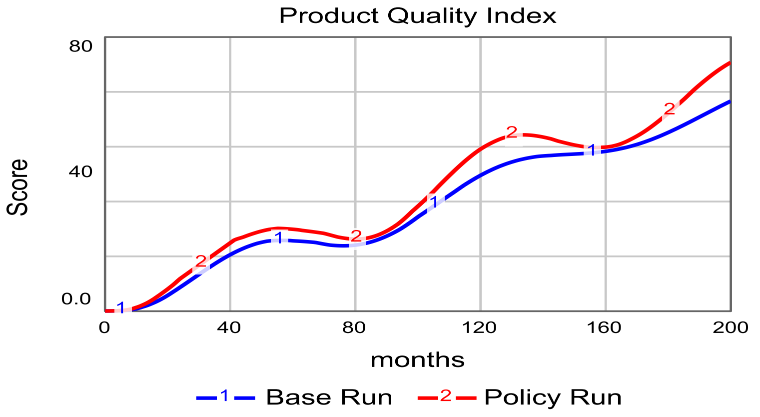
Graph7. Comparison of QCC Projects between base run and policy run



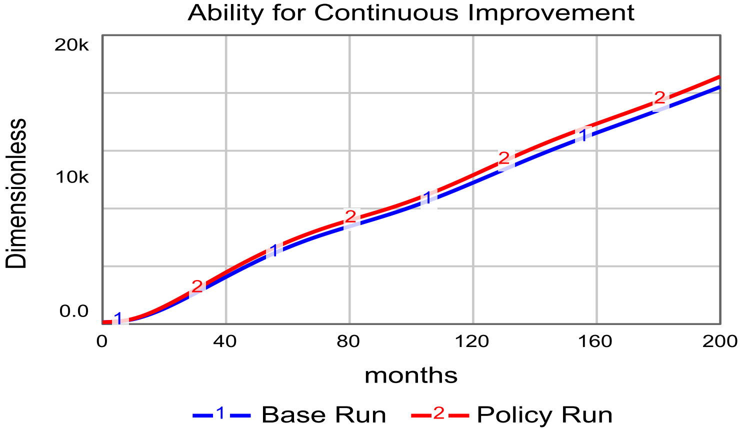
Graph 8. Comparison of Projects savings between base run and policy run



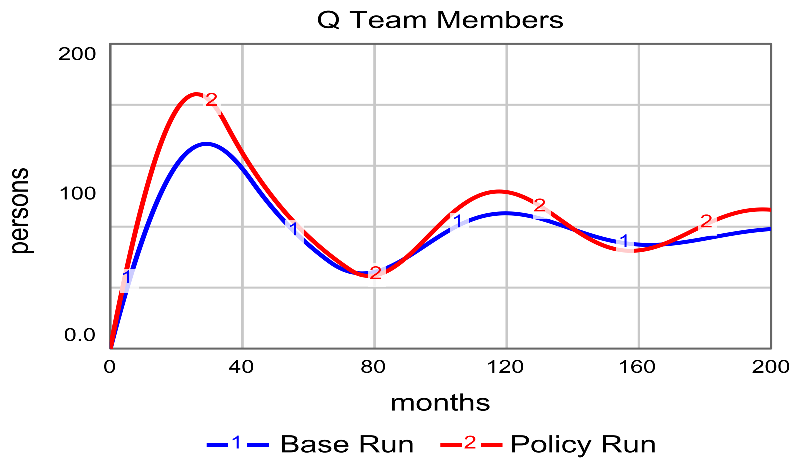
Graph 9. Comparison of Product Quality Index between base run and policy run



Graph 10. Comparison of Quality Team Members between base run and policy run



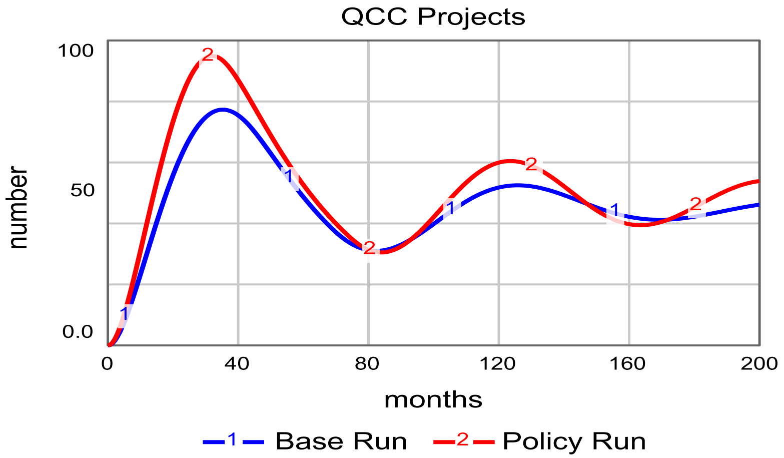
Graph 11. Comparison of Ability for Continuous Improvement between base run and policy run



Graph 12. Comparison of Labour Productivity between base run and policy run

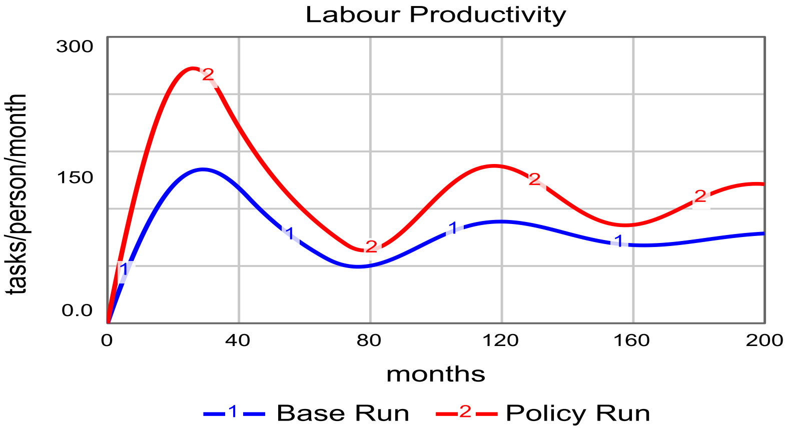
Policy Run 2 Enhance Employee Involvement (60 percent to 80 percent)

Employee involvement is the backbone of quality control circles. It is well-known that when employees are respected and empowered (Arrfou, 2019) to take the corrective measures, they show responsibility and try to come up to the aspirations of the management. This model depicts this story that as soon as the employee involvement is boosted on an interval scale (0 to 100 percent) from 60 percent to 80 percent there will be a significant improvement in every factor such as the number of projects, savings generated, improvement in product quality index, and rising labour productivity. See graph 13 to 17 to understand this trend. Employee involvement does not depict the spiral behaviour because employee involvement capacity is limited by multiple constraints like time assigned, motivation level, and overall potential.



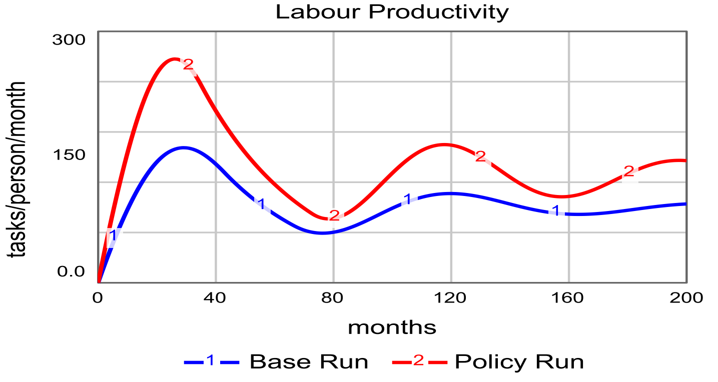
Graph 13. Comparison of Q Team Members between base run and policy run

Graph 14. Comparison of QCC Projects between base run and policy run



Graph 15. Comparison of Projects Savings between base run and policy run

Graph 16. Comparison of Product Quality Index between base run and policy run



Graph 17. Comparison of Labour Productivity between base run and policy run

6. Conclusion

Policy analysis indicates that human capital can be converted into financial capital while generating project savings. It is possible through the careful development of the model and intelligent implementation of quality control circles. The code of conduct and seven steps strategy require the deployment in a conducive environment. Employee involvement (Hill, 1991) and management focus are the key parametric variables that contribute substantially to the success of the quality control circles. The result of the model is obvious that awareness sessions, motivational drive, and training are the operational instruments to enhance employee involvement and make the quality circles success stories within the company. Increasing members of the QCC projects enhance labour productivity and then gradually settle down as the human potential reaches its maximum limit within the given resources. Project savings are on the track of improvement and keep on increasing with the completion of each project. Project completion and projects savings are the driving forces to break the inertia in a system and further increase management focus for quality culture and environment of learning.

The model can be generalized for studying the underlying structure of various companies and changing initial conditions like

SPELL Packaging, KSB pumps, Indus Motors, Descon Engineering, Irfan Textile, and Thal Engineering. By changing the initial conditions of any company, the model can be used for that company and the behaviour generated will be the sinusoidal oscillatory waveform for QCC projects, QCC team members, and labour productivity whereas the behaviour of project savings and product quality index depicts the spiral growth. It has been revealed that the underlying structures and feedback concepts of the companies remain the same as per the seven-step strategy model.

Experimentation can be done with the model to explore more entry points for parametric based policy interventions and to find out the more plausible policies. New structures based on innovative and creative thinking can be added after gaining insight while playing with the simulation model to design the policies based on structural changes. Sensitivity analysis of the model can be taken as a future research agenda to make the model more robust and generic.

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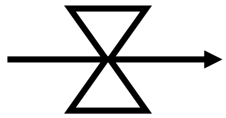
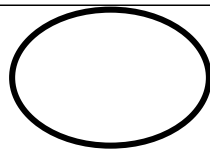
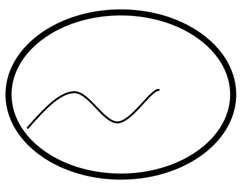
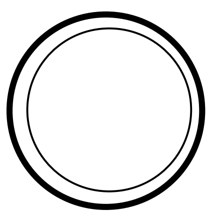
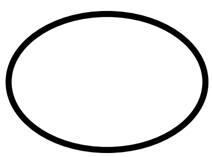
Appendix A

STELLA is a simulation software named as the "Structured Thinking Experiential Learning Laboratory Animation (STELLA)". Following is the detail of symbols used in modelling language

Table (1)

Symbols for Flow Diagram in STELLA

Description	Symbol	Associated Equation Type	Explanation
Level		L	Stock
Rate		R	Flow
Auxiliary		A	Convertor
Graphical Function / Table Function		T	Perception map between two variables on x-y plane
Exogenous variable		E	Occasionally affect the model behavior but not part of model
Constant		**C**	Constant which has unique value and which is prone to change.
Source or Sink of Material		Define	Out of boundary, defines the model scope
Material / Information Flow			Use for the movement of material and information

Appendix B

List of Variables

Variables	Description	UOM	Equation Type	Base Run Parametric Value
Initial QCC Projects	Initial QCC Projects	Number	C	0
QCC Projects	QCC Projects	Number	L	
Initial Projects Savings	Initial Projects Savings	Rupees	C	0
Projects Savings	Projects Savings	Rupees	L	
Initial Q Team Members	Initial Q Team Members	Persons	C	0
Q Team Members	Q Team Members	Persons	L	
Joining Time	Joining Time	Months	C	10
Members Leaving Time	Members Leaving Time	Months	C	36
SS Training	SS Training	Hours	C	1000
HS Training	HS Training	Hours	C	1000
Normal Labour Productivity	Normal Labour Productivity	Tasks per person per month	C	1
Normal Employee Involvement	Normal Employee Involvement	Dimensionless	C	0.5
Employee Involvement	Employee Involvement	Dimensionless	C	0.6
Themes	Themes	Number of Ideas	C	20
Normal Quality	Normal Quality	Dimensionless	C	0.7
Management Pressure Initial	Management Pressure Initial	Dimensionless	C	0.7
Project Team Size	Project Team Size	Number per person	C	0.25
Project Completion Time	Project Completion Time	Months	C	6
Potential Members	Potential Members	persons	C	100
TTPG	Time to cover potential members	Months	C	24
Learning Fraction	Learning Fraction	Per month	C	0.020

Initial Ability for Continuous	Initial Ability for Continuous	Dimensionless	C	125
Ability for Continuous	Ability for Continuous	Dimensionless	L	
AIR	Ability Increase Rate	Dimensionless	R	
MJR	Member Joining Rate	Persons/month	R	
MLR	Member Leaving Rate	Persons/month	R	
QCCSR	Quality Control Circle Start Rate	Number/month	R	
QCCIMR	Quality Control Circle Implementation Rate	Number/month	R	

Note: Rupee is the abbreviation of Pakistani Currency**.**

Appendix C

STELLA is simulation software named as the Structured Thinking Experiential Learning Laboratory Animation (STELLA)

Followings are the equations written in STELLA

Top-Level Model:

Ability_for_CI(t) = Ability_for_CI(t - dt) + (AIR) * dt
INIT Ability_for_CI = Initial_Ability
INFLOWS:
AIR = New_Ideas*(HS_Training+SS_Training)*Effect_SQC_Tools/8*.25
Projects_Savings(t) = Projects_Savings(t - dt) + (Saving_Rate) * dt
INIT Projects_Savings = Initial_Project_Savings
INFLOWS:
Saving_Rate = QCCIMR*100000/3
Q_Team_Members(t) = Q_Team_Members(t - dt) + (MJR - MLR) * dt
INIT Q_Team_Members = Initial_Q_Teams_Members
INFLOWS:
MJR = Perceied_Gap*"Management_Pressure-CI"/Joining_Time
OUTFLOWS:
MLR = Q_Team_Members/Member_Leaving_Time
QCC_Projects(t) = QCC_Projects(t - dt) + (QCCSR - QCCIMR) * dt
INIT QCC_Projects = 0
INFLOWS:
QCCSR = Themes*Q_Team_Members*(Fraction_Learning)*Project_Team_Size
OUTFLOWS:
QCCIMR = QCC_Projects/Project_Completion_Time
Effect_SQC_Tools = GRAPH(SQC_Tools)
(0.000, 0.075), (0.700, 0.116), (1.400, 0.177), (2.100, 0.242), (2.800, 0.333), (3.500, 0.437), (4.200, 0.554), (4.900, 0.688), (5.600, 0.840), (6.300, 0.965), (7.000, 0.965)
Employee_Involvement = 0.80
Fraction_Learning = 0.020
HS_Training = 1000
Initial_Ability = 125
Initial_Project_Savings = 0
Initial_Q_Teams_Members = 0
Joining_Time = 10
Labour_Productivity = Normal_Productivity*Ratio_Employee_Involvement*Q_Team_Members
Management_Pressure_Initial = 0.7
"Management_Pressure-CI" = Ratio_Employee_Involvement*Management_Pressure_Initial
Member_Leaving_Time = 36
Members_Gap = Potential_Members-Q_Team_Members
New_Ideas = 2
Normal_Employee_Involvement = .5
Normal_Productivity = 1
Normal_Quality = 0.7
Perceied_Gap = SMTH3(Members_Gap,TTPG)
Potential_Members = 100

Product_Qualitiy_Index = Normal_Quality*Effect_SQC_Tools*Ratio_ACI
Project_Completion_Time = 6
Project_Team_Size = 0.25
Ratio_ACI = Ability_for_CI/Initial_Ability
Ratio_Employee_Involvement = Employee_Involvement/Normal_Employee_Involvement
SQC_Tools = GRAPH(QCC_Projects)
(0.0, 0.000), (10.0, 1.416), (20.0, 2.727), (30.0, 3.854), (40.0, 4.483), (50.0, 4.981), (60.0, 5.427), (70.0, 5.768), (80.0, 6.082), (90.0, 6.554), (100.0, 6.869)
SS_Training = 1000
Themes = 20
TTPG = 24
{ The model has 38 (38) variables (array expansion in parens).
In 1 Modules with 1 Sectors.
Stocks: 4 (4) Flows: 6 (6) Converters: 28 (28)
Constants: 19 (19) Equations: 15 (15) Graphicals: 2 (2)
There are also 10 expanded macro variables.}